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Estimates of the Economic Effects of Sea Level Rise

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Abstract. Regional estimates of direct cost (DC) are commonly used to measure the economic damages of sea level rise. Such estimates suffer from three limitations: (i) values of threatened endowments are not well known, (ii) loss of endowments does not affect consumer prices, and (iii) international trade is disregarded. Results in this paper indicate that these limitations can significantly affect economic assessments of sea level rise. Current uncertainty regarding endowment values (as reflected in two alternative data sets), for example, leads to a 17 percent difference in coastal protection, a 36 percent difference in the amount of land protected, and a 36 percent difference in DC globally. Also, global losses in equivalent variation (EV), a welfare measure that accounts for price changes, are 13 percent higher than DC estimates. Regional EV losses may be up to 10 percent lower than regional DC, however, because international trade tends to redistribute losses from regions with relatively high damages to regions with relatively low damages.

Key words: direct cost, economic impacts, equivalent variation, sea level rise

JEL classification: D58, Q00, Q24

1. Introduction

Sea level rise is among the most profound impacts of climate change. Thermal expansion of ocean waters and melting of land-ice due to higher ambient temperatures would lead to a rise in the average sea level by about 50 cm by the end of the next century (Warrick et al. 1996). Human activities cluster near low-lying coasts because of the fertility of land in deltas, proximity of sea food, and transport opportunities. The coastal zone is also one of the most productive and diverse natural areas (Vellinga and Leatherman 1989). Even a relatively modest sea level rise would thus have a substantial effect on human society, unless, perhaps costly, protective measures are undertaken (Bijlsma et al. 1996). A number of studies have tried to quantify the impacts of sea level rise (Fankhauser 1994; Hoozemans et al. 1993; Leatherman and Nicholls 1995a, b; Nicholls 1995; Nicholls and Hoozemans

1996; Nicholls and Mimura 1998; Nicholls et al. 1995; Yohe et al. 1995, 1996; Yohe and Schlesinger 1998). These studies are far from perfect: data bases are rough and incomplete, and methods used are crude (Bijlsma et al. 1996). The studies are also less than satisfactory from an economic point of view. Human adaptation, for example, is either absent or unrealistically sophisticated (West et al. 1998).

Another shortcoming is that welfare estimates are often confined to direct cost (DC) – the value of land and/or capital lost plus investments is coastal protection. Such estimates suffer from three limitations. First, the value of land and capital located in coastal areas threatened by sea level rise is not well known. Because of their influence on the optimal level of coastal protection, different assumptions about land and capital values have an indirect as well as an immediate effect on DC estimates. Second, DC is only a first order approximation of welfare losses. By assuming constant prices, it neglects second order effects. Third, DC is generally estimated for specific regions in isolation. Because of international trade, however, the economic impacts of sea level rise are likely to spill across regional and national boundaries and affect areas with little or no immediate damages. The purpose of this paper is to illustrate and evaluate the extent to which these limitations may distort estimates of the economic losses that might be generated by sea level rise.

2. Procedures

We illustrate the limitations of the DC method with two models – the *Climate Framework for Uncertainly, Negotiation and Distribution* (*FUND*; cf. Tol 1997, 1999a–e) and the *Future Agricultural Resources Model* (*FARM*; cf. Darwin 1999; Darwin et al. 1995, 1996). By combining values of land and capital with per-unit costs of coastal quantities and costs of dryland and wetland lost to sea level rise. We use *FUND* to estimate and compare the effects of different assumptions about land and capital values on these optimal levels. *FARM* contains a twelve-region geographical information system (GIS) that estimates the type of land lost to sea level rise and an eight-region computable general equilibrium (CGE) economic model that estimates DC and equivalent variation (EV), a welfare measure that also accounts for second order economic effects. Because *FARM*'s CGE economic model is global, it also simulates international trade. Hence, we use *FARM* to estimate and compare DC with EV and to evaluate cross-boundary spillovers due to international trade.

2.1. Potential geophysical impacts of sea level rise

The impacts of a 0.5-m rise in sea level are evaluated in the twelve regions defined in *FARM*'s GIS (see Table I). For each region, Table II presents estimates of the length of coast at risk, the potential dryland loss without protection, the potential wetland loss without protection, and the additional potential wetland loss if full

Table I. Description of the regions.

Acronym	Name	Description
USA	United States of America	United States of America
CAN	Canada	Canada
EC	European Community	12 members countries of EC in 1990
JPN	Japan	Japan
ANZ	Australia and New Zealand	Australia and New Zealand
OEA	other East Asia	South Korea, China, Hong Kong, Taiwan
SEA	South East Asia	Indonesia, Malaysia, Philippines, Thailand
LA[a]	Latin America	Latin America
OE[a]	other Europe	European countries not in EC and former Soviet Union
fSUM[a]	former Soviet Union and Mongolia	former Soviet Union and Monoglia
OAO[a]	other Asia and Oceania	Middle East, South Asia, and Oceania
AFR[a]	Africa	Africa

[a] *FARM*'s Computable General Equilibrium economic model groups these regions into one "Rest of the World" region. *FARM*'s Geographical Information System, however, does track some information about these regions so as to conduct partial equilibrium analyses.

protection for dryland were implemented. The coast length of all countries in the world was taken from the Global Vulnerability Assessment (GVA) by Hoozemans et al. (1993), an update of work earlier done for the Intergovernmental Panel on Climate Change (IPCC CZMS, 1990, 1991). Other sources, such as the proceedings of the 1993 World Coast Conference (Bijlsma et al. 1994), Nicholls and Leatherman (1995a, b) and Fankhauser (1994) use (occasionally widely) different estimates of the length of the coast of particular countries. However, the length of a coast depends on the measurement procedure. The GVA is based on an internally consistent, globally comprehensive data set and therefore used here. Threatened coastlines are small portions of the total coastlines of the various regions (cf. Figure 3.1 of Hoozemans et al. 1993). The land area threatened ranges from 0.01 percent in Canada to 1.03 percent in Southeast Asia for an overall average of 0.25 percent.

Wetland losses for a 0.5-m sea level rise were taken from the GVA and, where available, replaced with results from country studies as reported by Bijlsma et al. (1996) and some additional studies reported by Nicholls and Leatherman (1995a, b) and Beniston et al. (1998). The reasons are this: (i) the GVA is a desk study which occasionally shows signs of the great haste of its preparation; (ii) the country studies use local data; and (iii) land lost because of sea level rise is more obviously estimable than coast length. Bijlsma et al. (1996), however, only report wetland losses in the absence of coastal protection. The GVA reports wetland losses both with and without coastal protection for all countries. The country-specific ratio between the two was used to derive wetland losses with protection according to Bijlsma et al. (1996).

Table II. Coastline, dryland and wetland threatened by a 0.5 metre sea level rise.

Region	Coastline (km)	Dryland (km^2)	Wetland (km^2)	Wetland[a] (km^2)
USA	28,716	10,000	5,700	395
CAN	4,554	485	0	0
EC[b]	32,788	1,962	1,605	451
JPN	4,463	1,150	287	4
ANZ	18,415	1,568	128	92
OEA	27,768	17,694	2,940	890
SEA	29,808	22,907	7,341	2
LA	39,233	28,515	22,892	2,578
OE	28,850	1,089	19	1
fSUM	22,097	7,569	0	0
OAO	77,018	90,129	24,130	0
AFR	34,665	67,477	15,248	173

[a] Additional wetland threatened by full protection.

Dryland losses are not reported in the GVA, but they are by Bijlsma et al. (1996). The GVA reports people-at-risk, which is the number of people living in the one-in 1000-year flood plain, weighted by the chance of inundation. Combining this with the GVA's coastal population densities, area-at-risk results. The relationship between area-at-risk and land loss for the 18 countries in Bijlsma et al. (1996) was used to derive land losses from the GVA's area-at-risk for the other countries. We used the geometric mean of the ratio between Bijlsma's area-at-risk and land loss as a correction factor. This procedure introduces additional uncertainty. The review of the SCOR Working Group 89 (1991) shows that land loss estimates due to climate change are not very accurate.

2.2. Values of Land, Capital, and Coastal Protection

Following Fankhauser (1994), the OECD average of dryland value in FUND was set at 2 million U.S. dollars per km^2. Regional values follow from correcting for GDP per km^2 (based on population density in the coastal zone, as reported by the GVA, and income per capita). The OECD average of wetland value was set at 5 million dollars per km^2, again following Fankhauser (1994). Regional wetland values follow from scaling with:

$$\frac{\left(\dfrac{GDP/Capita}{20,000}\right)}{\left(1+\dfrac{GDP/Capita}{20,000}\right)} \tag{1}$$

Table III. Assumed values of drylands, wetlands, and protection costs.

Region	*FUND*			*FARM*		
	Protection[a] (10^6\$/km)	Dryland[b] (10^6\$/km^2)	Wetland[b] (10^6\$/km^2)	Dryland[b] (10^6\$/km^2)	Wetland[b] (10^6\$/km^2)	Capital[b] (10^6\$/km^2)
USA	3.3	1.56	5.90	0.53	0.013	0.84
CAN	2.8	0.16	5.92	0.02	0.002	0.01
EC	3.4	19.89	5.21	2.91	0.038	10.34
JPN	6.6	21.87	6.22	16.99	0.089	26.33
ANZ	2.0	0.12	5.29	0.08	0.002	0.07
OEA	5.9	0.74	0.34	0.66	0.001	0.49
SEA	1.6	0.31	0.49	0.14	0.012	0.09
LA[c]	4.3	0.26	0.78	0.06	0.009	0.03
OE[c]	1.6	1.49	1.75	0.38	0.005	0.20
FSUM[c]	2.4	0.19	3.10	0.05	0.006	0.03
OAO[c]	4.1	0.43	0.26	0.11	0.001	0.06
AFR[c]	3.0	0.31	0.30	0.08	0.001	0.04

[a] Total, undiscounted costs of protection against a 1 metre sea level rise in 100 years, as reported by Hoozemans et al. (1993).
[b] Net present value, based on an effective discount rate of 1% and an infinite time horizon; see text for derivation.
[c] *FARM*'s CGE model groups these regions into one 'rest of the world'. Aggregate net present values are 0.26, 0.003 and 0.14 million \$/km^2 for dryland, wetland, and capital, respectively. Regional values are interpolated proportionally to the dryland values of *FUND*.

which is scaled to unity for the OECD in 1990. The costs of coastal protection follow from the GVA, again where possible replaced by country study results. Table III shows the values.

In *FARM*, land in each region is assigned to up to six climate-defined classes. Land in each land class is further divided into five major uses and/or covers – cropland, grazing land, forest land, land used in producing other economic goods and services (e.g., urban, suburban, and industrial land), and "other" land (i.e., deserts, barren wilderness, and wetlands). Total annual regional returns to land services for cropland and grazing land are derived from cost data in the Global Trade Analysis Project (GTAP) database (Hertel 1993). These total returns are distributed to the land classes based on each land class's respective contributions to crop and livestock production. Average rents for these two uses by land class are obtained by dividing returns per use per land class by the number of hectares per use per land class.

Returns to forest land in *FARM* are approximately one third the returns to pasture. Rental values for urban, suburban, and industrial land in the current version of *FARM* are approximately equal to cropland rents. This assumption is based n the opportunity cost principle, e.g., that the cost of land used for urban and industrial purposes is the value that land would have if it were used for other purposes, in this case, growing crops. Using cropland rents for opportunity costs isolates the biologically based productive capacity of urban land from its productive capacity due to the proximity of large capital aggregates. Returns to “other” land are assumed to be one-tenth the returns to forest land and are added to returns to land in the services sector. The end result is that each region’s land is treated as a heterogeneous good and each land-use-land-class combination has its own price.

Each land-use-land-class combination also is associated with an unknown quantity of homogeneous capital, which also generates an annual return. Total annual regional returns to capital for 13 commodities are derived from cost data in the GTAP database (Hertel 1993). Returns by commodity are distributed to the land classes based on each land class’s share of commodity production. Cropland produces three commodities: 1) wheat, 2) other grains, and 3) non-grains. Pasture and forestland produce livestock and forest products, respectively. Urban, suburban, and industrial land produces eight commodities: 1) coal, oil, gas, 2) other minerals, 3) fish, meat, milk, 4) other processed foods, 5) textiles, clothing, and footwear, 6) other nonmetallic manufactures, 7) other manufactures, and 8) services. Average per-hectare capital returns by use and land class are obtained by dividing returns per use per land class by the number of hectares per use per land class. Because it supports relatively large aggregates of capital, urban, suburban, and industrial land is associated with greater returns to capital per hectare than land used for other purposes. Returns to capital on desert, barren wilderness, and wetlands are zero because capital is assumed to be absent on such land.

The distribution of land at risk due to sea level rise by region, class, and use is derived with *FARM*’s GIS by combining 10-minute resolution altitude data (U.S. Navy, Fleet Navigational Operations Center 1992) with land-use and land-cover data (Olson 1992) and *FARM*’s land-class data. We use the land-class-land-use shares for dryland and wetlands implicit in this data to distribute *FUND*’s dryland and wetland losses across *FARM*’s land uses and land classes. Regional estimates of wetlands *FARM*’s coastal land are obtained with *FUND*’s ratios of wetland to total land at risk in each region. Wetlands are distributed according to the land-class shares of “other” land. All other *FARM* land types are dryland.

FARM’s wetland values in Table III are average values of all wetlands in the land classes at risk to sea level rise in a given region. They do not reflect the value of any environmental services that wetlands might provide. Hence they capture only a small portion (less than 1 percent) of the wetland values considered by *FUND*, which do include recreation and nature values. Dryland values are average values of all land not wetland in the land classes at risk. They reflect only 13 percent to 89 percent of the dryland values assumed by *FUND*. This is due in part because *FARM*’s rental values for urban, suburban, and industrial land only reflect its biologically-based productive capacity.

FARM’s capital values in Table III are average values of returns to fixed capital per km^2 in the land-use-land-class combinations at risk. “Fixed” capital is capital that could not be economically moved as sea leave rises. It consists primarily of buildings, roads, piers, and similar items found near the seashore. Returns to fixed capital are assumed to be equal to 0.5 total capital returns. The quantity per unit area (and hence its value per unit area) is assumed to increase at the same rate as land values in this analysis. Combining FARM's capital and dryland values together yields values that reflect 19 percent to 198 percent of FUND's dryland values. The relatively large differences between these values and the wetland values clearly indicates that there is considerable uncertainly about the values of endowments threatened by sea level rise.

2.3. Estimating the level of coastal protection

Given values of land and protection, *FUND* calculates optimal levels and costs of coastal protection as well as optimal quantities and costs of dryland and wetland lost to sea level rise. The fraction of land protected against sea level rise follows:

$$L = \max\left\{0, 1 - \frac{1}{2}\left(\frac{PC + WL}{DL}\right)\right\} \tag{2}$$

L is the fraction of the coastline to be protected. *WL* is the net present value of wetland lost due to full coastal protection. *DL* is the net present value of dryland lost to sea level rise. *PC* is the net present value of the protection if the whole coast is protected. See Fankhauser (1994) for the derivation of (2). He uses a very simple, large linear model so as to be able to express the optimal level of protection in closed-form. Below, we use simple expressions for the growth of dryland losses, wetland losses and protection costs so that their net present values can be expressed in closed form too.

The GVA reports average protection costs per year over the next century (see Table III). *PC* is calculated assuming annual costs to be constant. This is based on the following. First, the coastal protection decision makers anticipate a linear see level rise. Second, coastal protection entails large infrastructural works which last for decades. Third, the considered costs are direct investments only, and technologies for coastal protection are mature, that is, technologies and prices will not change substantially in the future.

WL is the net present value of the wetlands lost due to full coastal protection. Wetland values are assumed constant relative to income, reflecting how much current decision makers care about the non-marketed services and goods that get lost. The amount of wetland lost is assumed to increase linearly over time. *DL* denotes the net present value of the dryland lost if no protection takes place. Dryland values are assumed to rise at the same pace as the economy grows. The amount of dryland lost is assumed to increase linearly over time.

Throughout the analysis, a pure rate of time preference, ρ, of 1.0 percent per year is used. The actual discount rate lies thus 1.0 percent above the growth rate of the economy, g. The net present costs of protection PC are thus equal to:

$$PC = \sum_{t=1}^{\infty} \left(\frac{1}{1+\rho+g} \right)^t PC^a = \frac{1+\rho+g}{\rho+g} PC^a \tag{3}$$

where PC^a is the average annual costs of protection.

The net present costs of wetland loss WL follow from:

$$WL = \sum_{t=1}^{\infty} t \left(\frac{1}{1+\rho+g} \right)^t WL_0 = \frac{1+\rho+g}{(\rho+g)^2} WL_0 \tag{4}$$

where WL_0 denotes the value of wetland loss in the first year.

The net present costs of dryland loss DL are:

$$DL = \sum_{t=0}^{\infty} t \left(\frac{1+g}{1+\rho+g} \right)^t DL_0 = \frac{(1+g)(1+\rho+g)}{\rho^2} DL_0 \tag{5}$$

where DL_0 is the value of dryland loss in the first year.

2.4. Estimating the Costs of Sea Level Rise

As land and fixed capital are lost to sea level rise or as resources are diverted from other pursuits to coastal protection, the supply of consumer goods and services in a region declines relative to a no-sea-level-rise scenario. This results in lower production levels and higher prices. Direct cost is the value of land and/or capital lost plus investments in coastal protection. Direct cost is also equal to the value of consumer goods and service foregone (assuming constant prices) and so it provides an estimate of welfare change. This and the fact that it is relatively easy to calculate ensures its popularity in the literature (Cline 1992; Fankhauser 1994; Jansen et al. 1991; Nicholls and Leatherman 1995a, b; Nordhaus 1991; 1994; Rijsberman 1991; Titus 1992; Titus et al. 1991; Tol 1995, 1996; Yohe 1990, 1995, 1996).

In *FUND*, DC is calculated as the amount of wetland and dryland land lost times their respective values plus the length of coast protected times the costs of protection per km. *FUND*'s DC estimates are annuitised. Direct cost in *FARM* is calculated as the amount of wetland per land class lost times its value per land class, plus the amount of dryland per use per land class lost times its value per use per land class, plus the amount of dryland per use per land class lost times the amount of fixed capital returns lost per unit area per use per land class, plus the cost of coastal protection. The amount of wetland and dryland lost as well as the costs of coastal protection used in *FARM*'s calculations come from *FUND*. *FARM*'s DC estimates (including the cost of coastal protection from *FUND*) are annual.

Direct cost does not reflect the total value of consumer goods and service foregone as a result of sea level rise, however, because it does not take account of the higher prices that would be generated by the relatively large loss of land and capital resources. Higher prices mean that consumers will not only have fewer goods and services available to them, but also that each dollar spent on goods and services will buy less. The effects of changing prices is captured with equivalent variation (EV), another standard measure of welfare change. EV is the difference, in terms of money expenditure – in this case at pre-sea-level-rise prices – between the level of consumer satisfaction under sea level rise and the level of satisfaction under no sea level rise. Estimates of EV are provided by *FARM*'s CGE model for eight regions.

Direct cost also does not accurately capture the geographical distribution of welfare losses that sea level rise would generate. Lower production levels and the higher prices induced in one region will spill over into other regions through international trade. Because it simulates international trade in, as well as production of, 13 commodities, *FARM*'s regional estimates of EV reflect the geographical distribution of damages more accurately than do its regional estimates of DC. Hence a comparison of *FARM*'s DC and EV estimates provides information about the extent to which ignoring price changes and international spillovers generates affects the measurement of the potential damages of sea level rise.

FARM simulates sea level rise by reducing land and capital quantities by appropriate amounts. The total amount (km^2) of wetland and dryland lost are derived from *FUND*. The *FARM*'s GIS derives the amount of land lost by use and class and creates exogenous shocks (in percent change format) for *FARM*'s CGE model that are consistent with land's heterogeneity. *FARM*'s GIS also estimates the total annual returns to fixed capital lost by region. These lost capital returns are combined with *FUND*'s annual costs of coastal protection under the following assumptions: (i) capital is treated as a homogeneous factor in *FARM*, (ii) expenditures on structures that provide coastal protection are primarily returns to capital because their construction is capital intensive, and (iii) the construction and/or maintenance of these capital structures preclude the purchase of other capital structures. Regional percent changes of the combined total of lost returns from this homogeneous capital are equivalent to regional percent changes in lost capital itself, and, therefore, are utilized as the exogenous shocks to capital by *FARM*'s CGE model. The losses are imposed on 1990 conditions in a comparative static analysis. *FARM*'s CGE model is implemented and solved using GEMPACK (Harrison and Pearson 1996).

3. Results

We first present *FUND*'s estimates of the level of coastal protection and the corresponding land losses caused by a 0.5-m rise in sea level under two different assumptions regarding the values of land and capital endowments. We then present two sets of estimates of the economic costs of sea level rise. The first set contains

Table IV. Level of coastal protection, dryland losses, and wetland losses in response to a sea level rise of 0.5 m by source of endowment values and region[a].

Region	*FUND*'s land values			*FARM*'s land and capital values		
	Coastline[b] (%)	Dryland (km^2)	Wetland (km^2)	Coastline (percent)	Dryland (km^2)	Wetland (km^2)
USA	82	1,800	6,023	72	2,808	5,984
CAN	0	485	0	0	484	0
EC	92	163	2,019	80	386	1,967
JPN	97	38	290	98	27	290
ANZ	0	1,568	128	0	1,568	128
OEA	91	1.572	2,940	93	1,276	3,765
SEA	95	1,079	7,343	92	1,783	7,343
LA	83	4,755	25,040	49	14,535	24,156
OE	20	867	19	0	1,089	19
fSUM	0	7,569	0	0	7,569	0
OAO	90	5,144	24,130	82	16,073	24,130
AFR	86	9,442	15,396	56	29,475	15,345

[a] Estimated with *FUND* using results from equations (2), (4), and (5).
[b] Coastline threatened by sea level rise.

FUND's estimates of annuitised DC based on the assumptions used for the coastal protection estimates. The second set contains of DC and EV based on *FARM*'s endowment values. A short discussion of the results ends this section.

3.1. Levels of Coastal Protection

FUND's estimates of the percent of threatened coastline protected as well as the dryland and wetland lost to a 0.5 rise in sea level are presented in Table IV. Two sets of estimates are presented. The first set is based on *FUND*'s land values while the second set is based on *FARM*'s land and fixed capital values. Both sets rely on *FUND*'s protection costs. As the level of protection depends on the ratio of protection costs and the value of the threatened endowments (see Equation (2)) and as protection costs are the same in both the *FUND*-based and *FARM*-based estimates, the regional pattern of protection levels follows directly from the regional pattern of land values displayed in Table III.

For example, *FUND*-based levels of coastal protection are zero in three regions – Canada, Australia/New Zealand, and the former Soviet Union (plus Mongolia). *FARM*-based protection levels are zero in the same three regions plus other Europe. The latter is due to *FARM*'s relatively low initial values of dryland plus fixed capital in other Europe (Table III). *FARM*'s values of dryland plus fixed capital are lower than *FUND*'s dryland values in the six other regions where *FUND*-based protection levels are higher than *FARM*-based levels. Differences in coastline protection for these six regions range from 3 to 69 percent. In the two regions where *FARM*-based protection levels are higher than the *FUND*-based levels, *FARM*'s values of dryland plus fixed capital are larger than *FUND*'s dryland values. Differences in coastline protection in these regions are 1 and 2 percent. Overall, the amount of threatened coastline protected in the *FARM*-based scenario is 17 percent lower on average than that in the *FUND*-based scenario. As a result, the amount of total land lost in the *FARM*-based scenario is 36 percent higher than that in the *FUND*-based scenario.

A comparison of land lost in Table IV with land threatened in Table II indicates that coastal protection reduces the total amount of land lost to sea level rise. Reductions in losses are limited, however, to dryland. Wetland losses are greater if coastal protection is employed, especially in the US, EC, Other East Asia, and Latin America. Equation (2) indicates that coastal protection decrease as wetland values increase. We evaluate the magnitude of this phenomenon by estimating coastal protection levels using *FARM*'s values for dryland and fixed capital but *FUND*'s values for wetlands. Protection levels decline slightly relative to the case where all values are from *FARM* (not shown). The regions most affected by the higher wetland values were the United States and Latin America where protection of the threatened coastline dropped to 71 percent and 48 percent respectively. Higher wetland values did not affect the first two significant figures of coastal protection in the other regions. The change is small because the amount of wetland lost to coastal protection is relatively small (Table II).

3.2. ECONOMIC COST

Table V presents annuitised DC for a 0.5-m rise in sea level (with and without coastal protection) based on both *FUND* and *FARM*'s endowment values. As expected, annuitised costs with optimal protection are lower than net present costs without optimal protection, about 65 percent for *FARM*'s endowment values and about 75 percent for *FUND*'s endowment values. *FARM*-based DC is lower than *FUND*-based DC in all regions except Japan and Other East Asia, where *FARM*-based protection levels are higher than *FUND*-based protection levels. Without coastal protection, *FUND*-based DC is 77 percent higher than *FARM*-based DC. With coastal protection, *FUND*-based DC is 36 percent higher.

Table VI presents annual DC and lost EV based on *FARM*'s endowment values. Direct cost is composed of the cost of protection, fixed capital lost, and land lost. Annual protection costs are calculated with *FUND* and, given the linearity assumptions in this analysis, they would equal actual annual protection cost around 2050 when sea level rise is projected to rise 0.25 m. Values of fixed capital and land are from *FARM*. *FARM*'s per-km^2 values of these endowments (Table III), however, pertain to economic conditions in 1990. Because these values are expected to be higher in 2050, total DC based on an area inundated by a 0.25-m sea level rise would underestimate the 2050 damages. To compensate somewhat we assume that the area inundated conforms to a 0.5-m rise in sea level in 2100. These costs are

Table V. Annuitised direct cost (million dollars per year) for a 0.5 m rise in sea level rise by source of endowment values, level of coastal protection, and region[a].

	FUND's land values			*FARM*'s land and capital values		
	No protection[b]	Protection[c]	Wetlands[d]	No protection[b]	Protection[c]	Wetlands[d]
USA	2,772	1,317	653	1,697	1,162	1
CAN	14	14	0	2	2	0
EC	6,954	1,638	163	2,826	1,448	1
JPN	4,483	433	35	6,181	435	1
ANZ	34	34	13	31	31	0
OEA	9,289	2,329	19	11,400	2,348	0
SEA	5,061	693	68	3,062	678	2
LA	5,210	2,316	336	1,667	1,683	0
OE	290	324	1	93	93	0
fSUM	251	251	0	80	80	0
OAO	27,809	4,597	119	8,932	4,210	0
AFR	3,700	1,408	88	1,184	1,100	0
Total	*42,923*	*10,533*	*2,958*	*24,990*	*8,941*	*5*

[a] Estimated with *FUND* using equations (2)–(5).
[b] Value of dryland lost to sea level rise.
[c] Value of dryland lost to sea level rise, coastal protection, and wetland lost to coastal protection.
[d] Value of wetland lost to sea level rise, excluding wetland lost to coastal protection.

relatively small, especially in developed regions, when compared to total regional economic activity (e.g., total expenditures) in 1990. Direct cost for the first five regions listed in Table VI ranges from almost nothing to 0.009 percent of total expenditures in 1990. Direct cost for Other East Asia, South East Asia, and the rest-of-world is, respectively, 0.105, 0.077, and 0.049 percent of total expenditures in 1990.

Equivalent variation is estimated by *FARM*. World EV lost is \$4,956 million, approximately 13 percent higher than world DC, which is equal to \$4,395 million. The additional losses are not equally distributed across the regions. In developed regions, differences between EV losses and DC range from \$11 million to \$290 million (from 43 percent to 8,213 percent). In developing and rest-of-world regions, differences between EV losses and DC range from −\$227 million to \$28 million (from −10 percent to +4 percent).

3.3. Discussion

Table III indicates that there is considerable uncertainty in the value of endowments threatened by sea level rise. Results in Tables IV and V indicate that these differences can have significant effects on the level of coastal protection, the amount of land inundated, and overall costs that a given region might have to bear. This uncer-

Table VI. Annual direct cost and equivalent variation lost (million dollars per year) for a 0.5 m rise in sea level with coastal protection by region.

Region	Direct costs				Equivalent
	Protection[a]	Fixed Capital[b]	Land[c]	Total	Variation[d]
USA	343	50	17	410	585
CAN	0	0	0	0	11
EC	446	90	13	549	839
JPN	144	11	5	160	421
ANZ	0	1	1	3	18
OEA	763	8	9	781	809
SEA	220	3	4	226	233
ROW	2,017	117	133	2,267	2,040
LA	417	27	32	475	–
OE	0	2	2	3	–
fSUM	0	4	4	8	–
OAO	1,309	51	58	1,419	–
AFR	291	33	37	361	–
Total	3,933	280	182	4,395	4,956

[a] Estimated with *FUND* using equation (2) and *FARM*'s values for land and fixed capital.
[b] Combines land quantities estimated by *FUND* with *FARM*'s per-hectare fixed capital values.
[c] Combines land quantities estimated by *FUND* with *FARM*'s land values.
[d] Estimated with *FARM*.

tainty may also pertain to those regions for which both *FUND* and *FARM* assume that the value of threatened endowments is small. A more accurate assessment, for example, might find that the value of Canadian endowments threatened by sea level rise would be high enough to trigger a positive level of coastal protection.

Results in Table VI indicate that the DC approach provides inaccurate global and regional estimates of the economic impacts of sea level rise. Globally, DC is lower than EV because the former does not account for the higher prices that would be generated by the loss of endowments that sea level rise would induce around the world. Regionally, DC differs from EV not only because of rising prices but also because of spillovers generated by international trade. In general, trade between regions tends to redistribute losses from regions with relatively high damages to regions with relatively low damages. This principle may also apply to *FARM*'s ROW region, that is, EV losses would probably be smaller than DC in other Asia (plus Oceania) but larger than DC in other Europe and the former Soviet Union (plus Mongolia). It also means that regions without coastlines are likely to sustain some economic hardships from sea level rise.

Region-specific impacts on EV depend on the relative importance of land, labour, and capital as sources of income, the composition of exports and imports, and trade policies. This implies that the DC-EV comparison is subject to a few limitations. One limitation pertains to the uncertainty surrounding the value of endowments. Different regional estimates of DC, either in total or among endowments, would have led to different estimates of EV. Another limitation is that *FARM* imposes impacts of sea level rise projected for 2050 on 1990 conditions. Differences in regional growth rates, however, mean that the 2050 pattern of trade spillovers is likely to vary from the one depicted here.

4. Summary and Conclusions

Direct-cost estimates are commonly used to measure the economic damages of sea level rise. Such estimates suffer from three limitations: (i) values of threatened endowments are not well-known, (ii) loss of endowments does not affect consumer prices, and (iii) international trade is overlooked. We have shown that, because of these limitations, DC estimates may significantly misrepresent the economic losses that might be generated by sea level rise, globally and even more so regionally.

For many parts of the world there is considerable uncertainty about the value of land and capital endowments threatened by sea level rise. This is turn generates uncertainty about the level of coastal protection, the amount of land inundated, and overall DC that a given region might have to bear. In the example presented in this paper, differences in endowment values lead to a 17 percent difference in coastal protection, a 36 percent difference in the amount of land protected, and a 36 percent difference in DC when coastal protection was implemented. When coastal protection was not implemented, the difference in DC is 77 percent. One way to reduce this uncertainty is to obtain more accurate data on the value of land and capital in general. Ideally, values for both dryland and wetland would include market and non-market components. A related activity would be to obtain data on the value of water and labour (both market and household) endowments threatened by sea level rise.

As a worldwide phenomenon, climate-induced sea level rise is likely to cause significant losses in land and capital endowments in many regions simultaneously. The size and scope of these losses will induce a general increase in consumer prices that will generate economic costs above those considered by DC. In our example global EV-based damages are 13 percent higher than DC-based damages. At the same time, the response of international traders to differential changes in regional prices will tend to redistribute losses from regions with relatively high damages to regions with relatively low damages. This means that sea level rise is likely to reduce economic welfare even in land-locked regions. The only way to overcome these limitations is to substitute partial equilibrium analyses of isolated regions with general equilibrium analyses of the world as a whole.

Finally, because the experiments conducted for this analysis do not accurately depict reality in all respects, we recognize that our estimates of the potential economic damages of sea level rise may be seriously flawed. This possibility, however, should not detract one from the insights that the analysis in the paper provides. The objective of this research was to determine the extent to which limited knowledge of the value of endowments and inadequate modeling capabilities may affect economic assessments of sea level rise. Our results indicate that significant gains in accuracy are likely to be obtained with greater knowledge and improved modeling capabilities.

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